

## General Disclaimer

### One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.
- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.
- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.
- This document is paginated as submitted by the original source.
- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

NAS 5-11063  
NGR-21-002-224  
NGR-21-002-316

ANOMALY IN THE QUIET-TIME HELIUM SPECTRUM AT 1 MeV PER NUCLEON

G. Gloeckler, D. Hovestadt, B. Klecker,  
O. Vollmer and C. Y. Fan

Technical Report No.  
76-023

August 1975

(NASA-CF-145861) ANOMALY IN THE QUIET-TIME  
HELIUM SPECTRUM AT 1 MeV PER NUCLEON  
(Maryland Univ.) 23 p HC \$3.50 CSCI 03E

N76-14013

Unclass

G3/93 J1622



UNIVERSITY OF MARYLAND  
DEPARTMENT OF PHYSICS AND ASTRONOMY  
COLLEGE PARK, MARYLAND

# ANOMALY IN THE QUIET-TIME HELIUM SPECTRUM AT 1 MeV PER NUCLEON

G. Gloeckler

Department of Physics and Astronomy, University of Maryland

D. Hovestadt, B. Klecker and O. Vollmer

Max-Planck Institut für extraterrestrische Physik

C. Y. Fan

Department of Physics, University of Arizona

Received

## ABSTRACT

An unusual spectral feature and anomalously large abundance of helium between 0.6 and  $\sim 2$  MeV per nucleon observed during the most quiet time periods in 1974-75 indicate the presence of low energy helium of an unknown origin. Alphas below 0.6 MeV per nucleon and protons below 1.5 MeV have an  $E^{-1.8}$  spectrum and the proton to alpha ratio is about 30. These  $\leq 1$  MeV particles are found to be emitted continuously by the Sun even during its most inactive periods.

Subject headings: Cosmic rays-solar system-abundance,  
cosmic ray

## I. INTRODUCTION

Despite extensive investigation of low energy protons and alpha particles during solar quiet periods (times when the intensity of particles in a given energy interval reaches its minimum value) it has not been possible to establish whether these particles are predominantly of solar or galactic origin or have been accelerated to the observed energies in the heliosphere (Fan et al., 1968, 1970; Kinsey, 1970; Simms and Tuzzolino, 1973; Krimigis et al., 1973; Zamov, 1975). In this paper we report our observations of quiet-time protons and helium nuclei with energies as low as 300 keV per nucleon. We find that during quiet times the spectrum of helium between  $\sim 1$  and 3 MeV per nucleon has an unexpected hump and that the proton to alpha ratio is less than 5. The origin of this component of helium is at present unknown.

On the other hand, low energy protons ( $\leq 1.5$  MeV) and helium nuclei below  $\sim 0.6$  MeV per nucleon have differential energy spectra of the form  $E^{-1.8}$ , and the proton to helium ratio is about 30. Since, in addition, the most probable arrival direction is measured to be along the interplanetary magnetic field away from the Sun, we conclude that these low energy particles are continuously emitted by the Sun even during its most inactive periods.

## II. INSTRUMENTATION

Our measurements are made using the ULET sensor of the University of Maryland/Max-Planck Institut Experiment on the earth-

orbiting IMP-8 satellite. IMP-8 is a spinning spacecraft (spin period  $\sim 2.6$  sec, spin axis perpendicular to the ecliptic plane) in a nearly circular orbit with perigee of  $\approx 23$  earth radii and a period of about 12 days. ULET is a three element  $dE/dx$  vs  $E$  telescope which is pointing approximately perpendicular to the satellite spin axis, has a geometrical factor of  $0.53 \text{ cm}^2 \text{ sr}$  and an opening cone full angle of  $50^\circ$  (Hovestadt and Vollmer, 1971). The detector system consists of detectors D1, a  $130 \text{ } \mu\text{g}/\text{cm}^2$  thick flow-through proportional counter; D2, a conventional circular Au-Si surface barrier detector; and A2, a plastic scintillator anti-coincidence cup detector. This design enables us to obtain two-parameter pulse-height analysis and separately identify protons, helium isotopes and individual heavier elements having energies far below 2 MeV per nucleon, the low energy limit of most conventional  $dE/dx$  vs  $E$  telescopes using thin  $\Delta E$  solid state detectors. In addition to the pulse-height analysis information the  $D1D2 \langle A2 \rangle$  counting rate (corresponding primarily to protons between 0.43 and 1.5 MeV and alpha particles in the range 0.26 to 6.6 MeV per nucleon) is sectorized into four  $90^\circ$  quadrants and is read out once every 20 seconds.

### III. RESULTS

The coincidence counting rate  $D1D2 \langle A2 \rangle$ , averaged over three hours and all four sectors is plotted in Figure 1 for an eighty-four day period in 1973 and 1974. Although no solar flares

of importance 2 or above have been observed during this time period there is an unmistakable presence of low energy particles at all times (the ULET background is far below  $5 \times 10^{-4}$  counts per second --see caption of Figure 3). Their intensities vary slowly by factors of  $10^2$  to  $10^3$  over 10 to 20 day periods indicating in general a non-impulsive, quasi-steady emission by the Sun of less than  $\sim 1$  MeV protons and alpha particles. It is interesting to note that the earth's magnetosphere has little influence on the intensity of the low energy solar particles we observe. This is evident when one examines the behavior of the rate plotted in Figure 1 at the bowshock crossings of the satellite (boundaries of shaded regions) or when IMP-8 is inside the bowshock (shaded regions). No obvious discontinuities in the rate are seen near the bowshock crossings nor is there a systematic difference between the intensity inside and outside the magnetosphere.

During three rather short time periods (marked by solid bars in Figure 1) the particle intensity dips to the same average minimum value of about  $5 \times 10^{-3}$  counts per second which corresponds to a proton flux of about  $10^{-2}$  protons per ( $\text{cm}^2 \text{sec sr MeV}$ ). We have used data accumulated during these three periods and four similar time intervals (not shown) for our quiet time analysis. To exclude low energy particles accelerated in the earth's magnetosphere we have eliminated from our data set periods during which the 10 minute averaged D1D2 <A2> counting rate showed "spike" structures and

required that variations between consecutive 10 minute averages be consistent with statistical fluctuations.

In Figure 2 we show five polar plots of the angular distribution in the ecliptic plane of protons and alphas derived from the D1D2  $\langle A2 \rangle$  sector counting rates averaged over several days during the quiet-time periods. For reference we have indicated the respective locations of a model bowshock and magnetopause. The average interplanetary magnetic field direction, measured during identical time intervals by the Goddard magnetometer on IMP-8 (King, 1975) is indicated in polar diagrams on the left hand side of the figure.

It is evident from Figure 2(b) that the strongest unidirectional anisotropy is seen when the satellite is in the dusk side and farthest away from the bowshock in a region where the interplanetary magnetic field is least likely to connect with the magnetosphere. The anisotropy data [lower polar plot of Figure 2(b)] indicate that the particles are moving along the magnetic field from the solar direction. We note that when the satellite is near the bowshock (within about 10 earth radii) and particularly in the dawn side [Figure 2(a)] or near the subsolar point upstream from the bowshock [Figure 2(c)], the particle anisotropy is significantly modified. This shows the influence of the magnetosphere on low energy solar particles, especially where the field lines are likely to connect with the bowshock. We emphasize that due to our selection criterion

there is no substantial contribution of  $>430$  keV protons escaping from the magnetosphere as is evident from the nearly constant sector averaged rates (dashed circles in Figure 2). The fact that quiet-time particles are also seen in the tail [Figure 2(c)] is interesting in itself and implies a relatively easy access of low energy solar particles into this region of the magnetosphere.

Detailed spectral information is obtained from two-parameter pulse-height data summed during the quiet-time periods between October 1973 and March 1975. The  $\Delta E$  vs  $E$  matrix for ULET, showing the proton and alpha data, is displayed in Figure 3. One should note the relative absence of events in the low energy region (D2 channel number  $\leq 60$ ) of the helium track and a clustering of data points around D2 channel number 80 corresponding to an energy of  $\sim 1.5$  MeV per nucleon.

The differential energy spectra for protons and helium nuclei derived from the pulse-height data accumulated during quiet times are shown in Figure 4. The spectra represented by open and solid symbols correspond to the requirements that the average  $D1D2 \langle A2 \rangle$  rate be less than  $6 \times 10^{-3}$  and  $4 \times 10^{-3}$  counts per second, respectively. Thus, the proton spectrum represented by solid triangles corresponds to conditions during the least active periods in the quiet-time intervals. While the proton spectrum is consistent with a power law of the form  $E^{-1.8}$ , the helium spectrum shows a hump around 1 MeV per nucleon. The



proton to alpha ratio is about 20 to 30 below  $\sim 0.6$  MeV per nucleon but drops to only 4 to 5 in the energy region of the hump. Furthermore, a more stringent selection of quiet-time intervals shows no spectral changes for protons, but a drop by about a factor of two in the intensity of helium at the hump.

#### IV. DISCUSSION

Where do the low energy particles we observe during the most quiet-time periods originate? Two cases are distinguished and discussed separately.

##### (a) Origin of Protons and Helium Nuclei Below $\sim 1$ MeV per Nucleon

For protons between 0.43 and 1.5 MeV and alpha particles below  $\sim 0.6$  per nucleon the simplest explanation consistent with our observations is that these energetic particles are continuously emitted by the Sun. In support of this conclusion we note that not only does the anisotropy data show them to be coming from the Sun [lower polar diagram of Figure 2(b)] but, in addition, the observed proton to alpha ratio of 30 is similar to the average value for solar flare particles and the solar wind. We rule out the possibility that protons of magnetospheric origin (Krimigis et al., 1974) contribute significantly to our measurements above 0.43 MeV, because the energy spectra of particles accelerated in the magnetosphere are considerably steeper (Fan et al., 1975) than

observed here. Furthermore, the anisotropy data of Figure 2(b) do not support a predominantly magnetospheric origin hypothesis above  $\sim 0.5$  MeV. On the other hand, we cannot as yet exclude the possibility that these low energy particles are accelerated in interplanetary space by, for example, second order Fermi processes (Murray et al., 1971; Jokipii, 1971). Wibberenz and Beuermann (1972) indeed estimate that such acceleration could be important near the Sun for  $\leq 1$  MeV per nucleon particles.

(b) Origin of the Anomalous Helium Nuclei Between 0.6 and  $\sim 3$  MeV per Nucleon

For helium nuclei above 0.6 MeV per nucleon no simple explanation comes to mind. We consider two alternatives.

Solar Origin. The observed correlation between the intensity of alpha particles between  $\sim 0.6$  and 2 MeV per nucleon and that of low energy protons (compare spectra represented by open and solid symbols in Figure 4) suggests that helium in this energy range may also come from the Sun. The hump could then be viewed as a flattening in the helium spectrum similar to that observed for C + O at lower energies and explained by coronal propagation and storage of these ions (Gloeckler et al., 1975a). Applying these ideas to the present case we can imagine the existence of regions in the Sun (different from those emitting  $< 1.5$  MeV protons and alphas below 0.6 MeV per nucleon) where particles, after being accelerated, are, on the average, stored for long time periods before being released.

For example, starting with an initial spectrum of helium of the form  $j(E) \propto E^{-4}$ , storage in the lower corona (at  $1.6 R_{\odot}$ ) at a temperature of  $\sim 1.2 \times 10^6$  °K for  $5 \times 10^4$  sec and followed by adiabatic deceleration in interplanetary space by a factor of two will result in an alpha particle spectrum shown as the solid curve in Figure 4. Increasing the storage time to  $1.5 \times 10^4$  sec without changing any of the other parameters will give the spectrum shown by the dotted curve. It should be recognized that this process would flatten the proton spectrum in a similar fashion (Gloeckler *et al.*, 1975a) which is not observed. Therefore, the intensity of protons produced by this mechanism must be comparable or lower than that of the  $\alpha$ -particles and we are left with explaining the unusually large abundance of helium (or the absence of protons) in these source regions. Although it is difficult to find a simple explanation for helium to be so enriched, we note that anomalous compositions have been observed in  $\text{He}^3$ -rich events (Garrard *et al.*, 1973; Anglin, 1974) and, more recently, in iron-rich emissions from the Sun (Gloeckler *et al.*, 1975b).

Non-Solar Origin. Arguments in favor of a non-solar origin for helium above 0.6 MeV per nucleon may be based on the similarity in the spectral feature (hump) of helium and the anomalous oxygen below  $\sim 10$  MeV per nucleon (Hovestadt *et al.*, 1973, Klecker *et al.*, 1975) which is believed to be non-solar in origin. In addition,

the low proton to  $\alpha$ -particle ratio above 2 MeV per nucleon (only about 2 to 5, see Figure 5), and studies of the 11-year variation in the flux of 6 MeV per nucleon quiet-time helium nuclei (Fan et al., 1970; Zamov, 1975) suggest a non-solar origin. Acceleration in the interplanetary medium of interstellar gas ionized within the heliosphere (Fisk et al., 1974) could qualitatively account for the observed features in the helium spectrum. One should bear in mind, however, that quiet-time helium already has an unusual spectral feature between  $\sim 5$  and 70 MeV per nucleon (Garcia-Munoz et al., 1973; Van Hollebeke et al., 1973) and that, unlike for the case of oxygen, the hump we find at lower energies is an additional anomaly which must be accounted for by any non-solar origin models (see Figure 5).

## VI. SUMMARY AND CONCLUSIONS

Low energy (0.43 to 1.5 MeV) protons are observed to be continuously present during quiet-time periods between October 1973 and March 1975. We find that in general the earth's magnetosphere has little influence on the intensity of these particles and that, in particular, they have easy access to the outer regions of the magnetosphere. The spectrum of protons between 0.43 and 1.5 MeV has the form  $E^{-1.8}$  and while the absolute intensity is somewhat variable during quiet-time periods, the spectral shape remains unchanged within the errors of our measurements. On the basis of

the measured anisotropies, spectra and abundances we conclude that these low energy quiet-time protons are very likely of solar origin.

The measured quiet-time helium spectrum is more difficult to explain. We argue that below  $\sim 0.6$  MeV per nucleon helium nuclei come from the Sun from presumably the same source regions which produce the protons. Between 0.6 and  $\sim 3$  MeV per nucleon we find that the spectrum has an unexpected hump with the helium abundance increasing and remaining enhanced up to about 70 MeV per nucleon (see Figure 5). We speculate on the origin of this anomalous low energy helium but cannot decide at present whether these nuclei are of solar origin, have been accelerated in the heliosphere or are of galactic origin. Additional observations of low energy quiet-time particles extending over a large portion of the eleven-year solar cycle and over a large range of heliocentric distances are essential before one can distinguish between these alternatives.

We are grateful to the many individuals at the University of Maryland and the Max-Planck Institut who have contributed to the success of our IMP-8 experiment. In particular, we thank P. Laeverenz, E. Kuenneth, E. Tums and J. Cain for designing and preparing the University of Maryland/Max-Planck Institut experiment for launch and acknowledge the programming efforts of J. Dalton and K. Hope. M. A. Davis and P. Butler of the IMP Project Office deserve our special thanks not only for their generous help during all phases of the program, but also for allowing us to modify our instrument

to emphasize the measurement of low energy ions and nuclei. This work has been supported by NASA under contract NAS 5-11063, grant NGR-21-002-224 and NGR-21-002-316, and by the German Government.

## REFERENCES

- Anglin, J. D. 1974, invited paper, American Physical Society Meeting, Chicago, February 1974.
- Fan, C. Y., Gloeckler, G., McKibben, B., Pyle, K. R., and Simpson, J. A. 1968, Canad. J. Phys., 46, S498.
- Fan, C. Y., Gloeckler, G., McKibben, R. B., and Simpson, J. A. 1970, Acta Physica Hungaricae, 29, Suppl. 2, 261.
- Fan, C. Y., Gloeckler, G., and Hovestadt, D. 1975, Phys. Rev. Letters, 34, 495.
- Fisk, L. A., Kozlovsky, B., and Ramaty, R. 1974, Ap. J. (Letters), 190, L35.
- Garcia-Munoz, M. 1973, Proc. 13th International Cosmic Ray Conference, University of Denver, August 17-30, Vol. 5, p. 3513.
- Garcia-Munoz, M., Mason, G. M., and Simpson, T. A. 1975, Ap. J. (in press).
- Garcia-Munoz, M., Mason, G. M., and Simpson, J. A. 1973, Ap. J. (Letters), 182, L81.
- Garrard, T. L., Stone, E. C., and Vogt, R. E. 1973, High Energy Phenomena on the Sun, Symposium Proceedings, ed. R. Ramaty and R. G. Stone (NASA SP-342), p. 341.
- Gloeckler, G., Sciambi, R., Fan, C. Y., and Hovestadt, D. 1975a, paper SP 2.1-4, 14th International Cosmic Ray Conference, Munich, W. Germany, August 18-28 (to be published).
- Gloeckler, G., Hovestadt, D., Vollmer, D., and Fan, C. Y. 1975b, Ap. J. (Letters), (in press).

- Hovestadt, D., Vollmer, O., Gloeckler, G., and Fan, C. Y. 1973, Phys. Rev. Letters, 31, 650.
- Hovestadt, D., and Vollmer, O. 1971, Proc. 12th International Conference on Cosmic Rays, Hobart, Tasmania, 16-25 August, Vol. 4, p. 1608.
- Jokipii, J. R. 1971, Phys. Rev. Letters, 26, 666.
- King, J. H. 1975, "Interplanetary Magnetic Field Data Book," NSSDC publication 75-04.
- Kinsey, J. H. 1970, Phys. Rev. Letters, 24, 246.
- Klecker, B., Hovestadt, D., Gloeckler, G., and Fan, C. Y. 1975, paper SP 2.2-8, Proc. 14th International Cosmic Ray Conference, München, W. Germany, August 18-28 (to be published).
- Krimigis, S. M., Armstrong, T. P., and Kohl, J. W. 1973, Proc. 13th International Cosmic Ray Conference, University of Denver, August 17-30, Vol. 2, p. 1656.
- Krimigis, S. M., Kohl, J. W., and Armstrong, T. P. 1974, Trans. Am. Geophys. Union, 56, 1165.
- Murray, S. S., Stone, E. C., and Vogt, R. E. 1971, Phys. Rev. Letters, 26, 663.
- Simpson, J. A., and Tuzzolino, A. J. 1973, Ap. J. (Letters), 185, L149.
- Van Hollebeke, M. A. I., Wang, J. R., McDonald, F. B. 1973, Proc. 13th International Cosmic Ray Conference, University of Denver, August 17-30, Vol. 2, p. 1298.
- Wibberenz, G., and Beuermann, K. P. 1972, Cosmic Plasma Physics, ed. K. Schindler (New York: Plenum), p. 333.
- Zamov, R. 1975, Ap. J., 197, 767.



---

C. Y. Fan: Department of Physics, University of Arizona, Tucson,  
Arizona 85721, USA.

G. Gloeckler, Department of Physics and Astronomy, University of  
Maryland, College Park, Maryland 20742, USA.

D. Hovestadt, B. Klecker, and O. Vollmer: Max-Planck Institut für  
extraterrestrische Physik, 8046 Garching b. München, W.  
Germany.

## FIGURE CAPTIONS

Fig. 1--Time variations in the intensity of 0.43 to 1.5 MeV protons. Each dot represents the mean value of the D1D2  $\langle A2 \rangle$  counting rate, averaged over all four sectors, during a three hour period. The six shaded regions indicate the time periods during which the satellite is inside the earth's bowshock. The intensity reached the same average minimum level ( $\sim 10^{-2}$  counts per sec) during the three time intervals marked by the three solid bars (days 10-11, 37-40 and 77 respectively).

Fig. 2--Polar plots of the angular distributions of the D1D2  $\langle A2 \rangle$  counting rate ( $\sim 80\%$  protons and  $20\%$  alphas) in the ecliptic plane. The left-hand side of the figure is towards the Sun and the orientation for all five polar diagrams is identical. Data for a given polar plot were averaged over the indicated segments of the IMP orbit. The scales are marked in units of ten earth radii. The coordinate system used had its origin at earth with the XSE-axis pointing towards the Sun, the YSE-axis towards the north ecliptic pole and the ZSE-axis completing a right-handed system. (a) anisotropy measurements in the dawn side, (b) anisotropy measurements in the dusk side, and (c) anisotropy measurements in the subsolar point and tail of the magnetosphere, respectively.

Fig. 3--Frequency distribution of the (D1,D2) pulse-height-channel-number pairs displayed as a  $\Delta E$  vs  $E$  matrix. The curve labeled "Helium" is derived from flight data accumulated during the September 1974 solar flare particle event. The residual

background (i.e., events below the protons and between the proton and helium tracks) is very low and amounts to at most a few per cent of the particle fluxes.

Fig. 4--Differential energy spectra for protons and helium nuclei during quiet times. The most outstanding feature is the hump in the helium spectrum around 1 MeV per nucleon.

Fig. 5--Differential energy spectra for quiet-time protons and helium nuclei. The solid and dashed curves are shown for reference. The data are from: ▲ (protons) ● (helium), this work; ◇ (protons) ⊖ (helium), Garcia-Munoz 1973; △ (protons) ○ (helium), Garcia-Munoz et al., 1975).

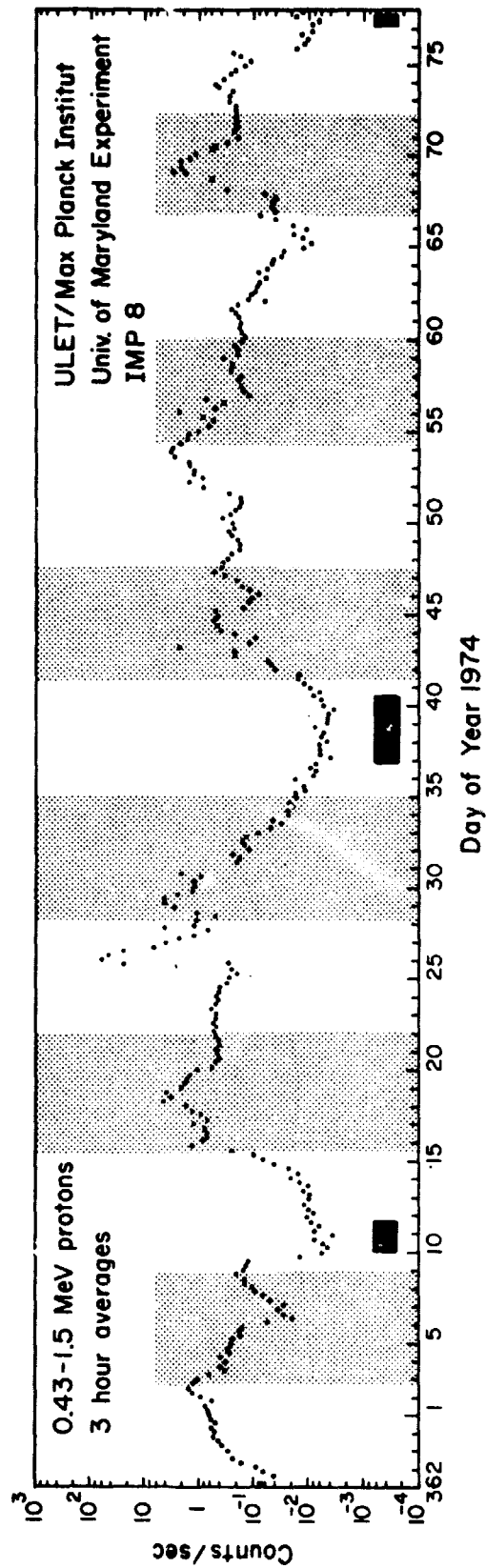


FIGURE 1

University of Maryland/Max Planck Institut Experiment  
ULET - IMP 8

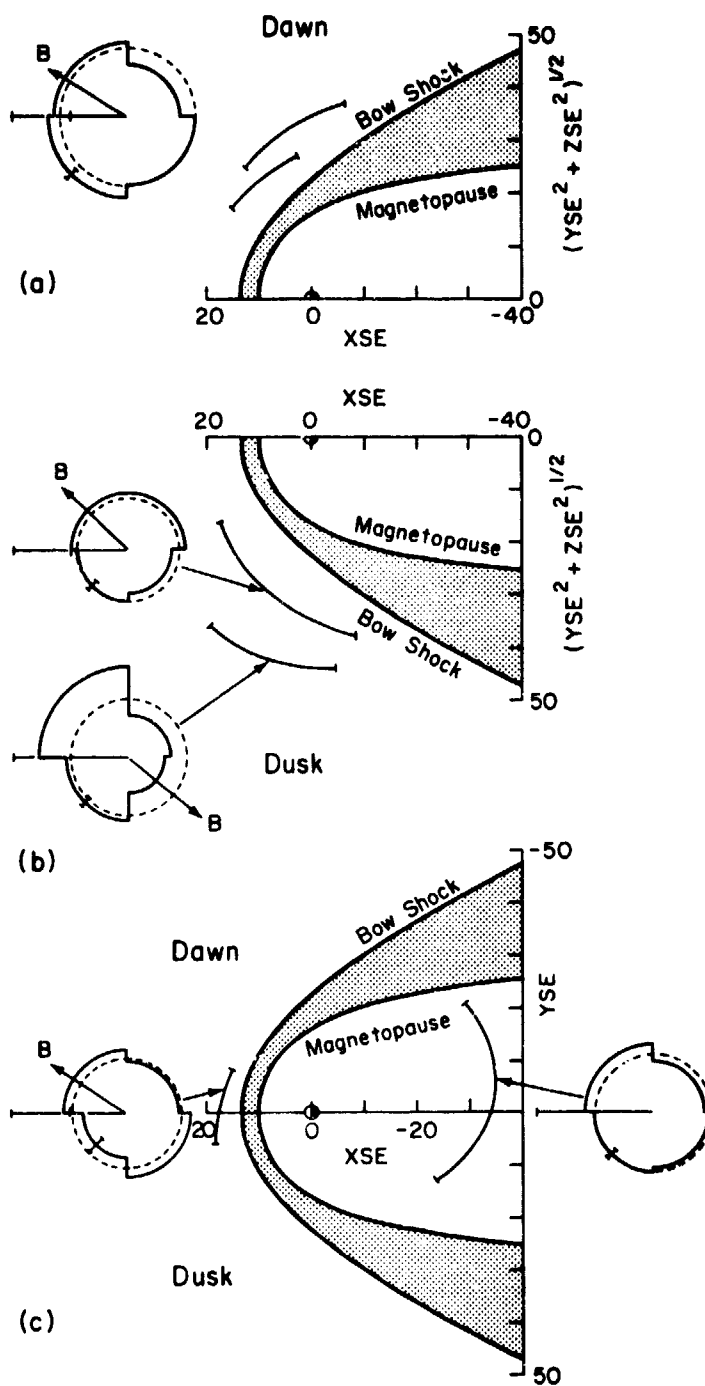


Fig. 2

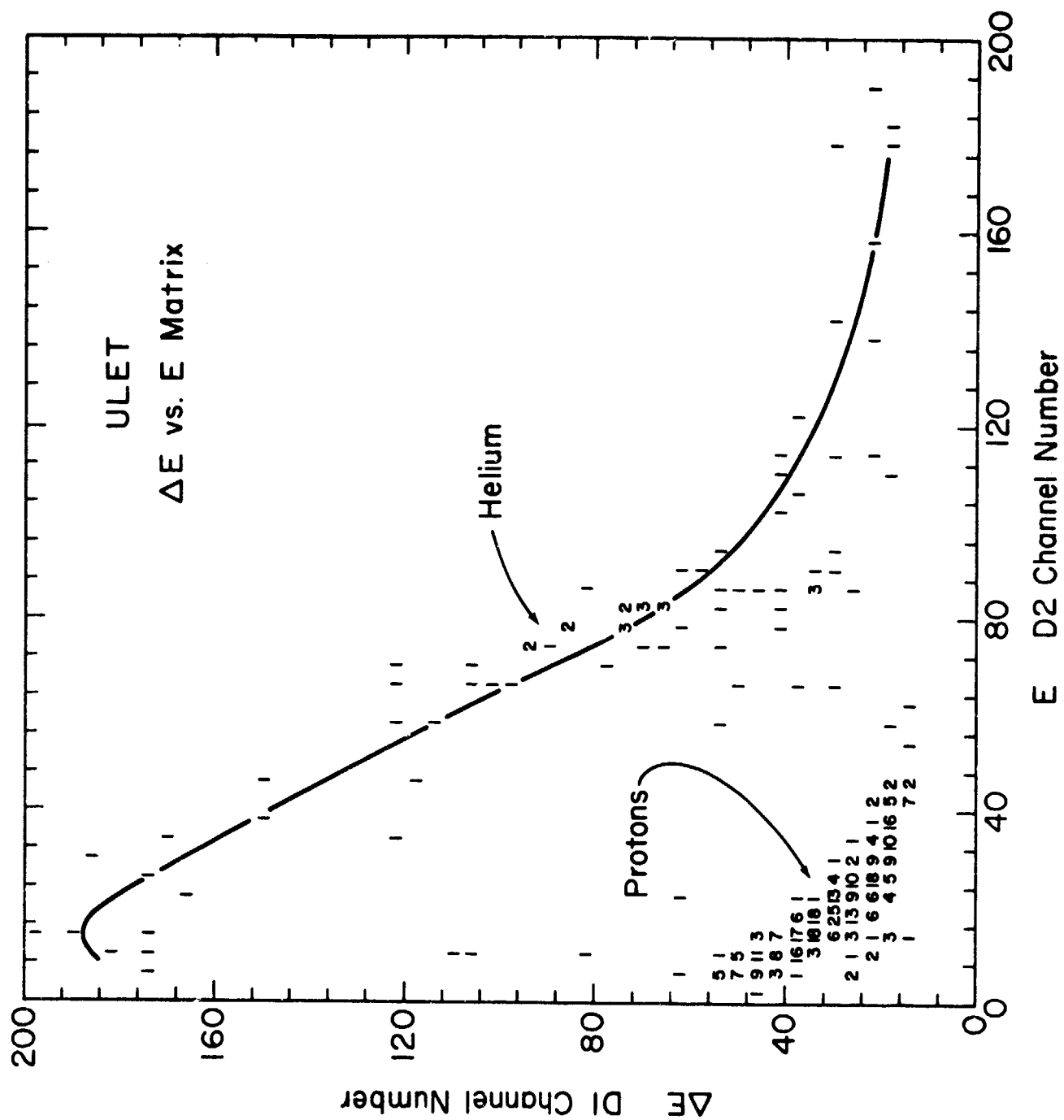


Fig. 3

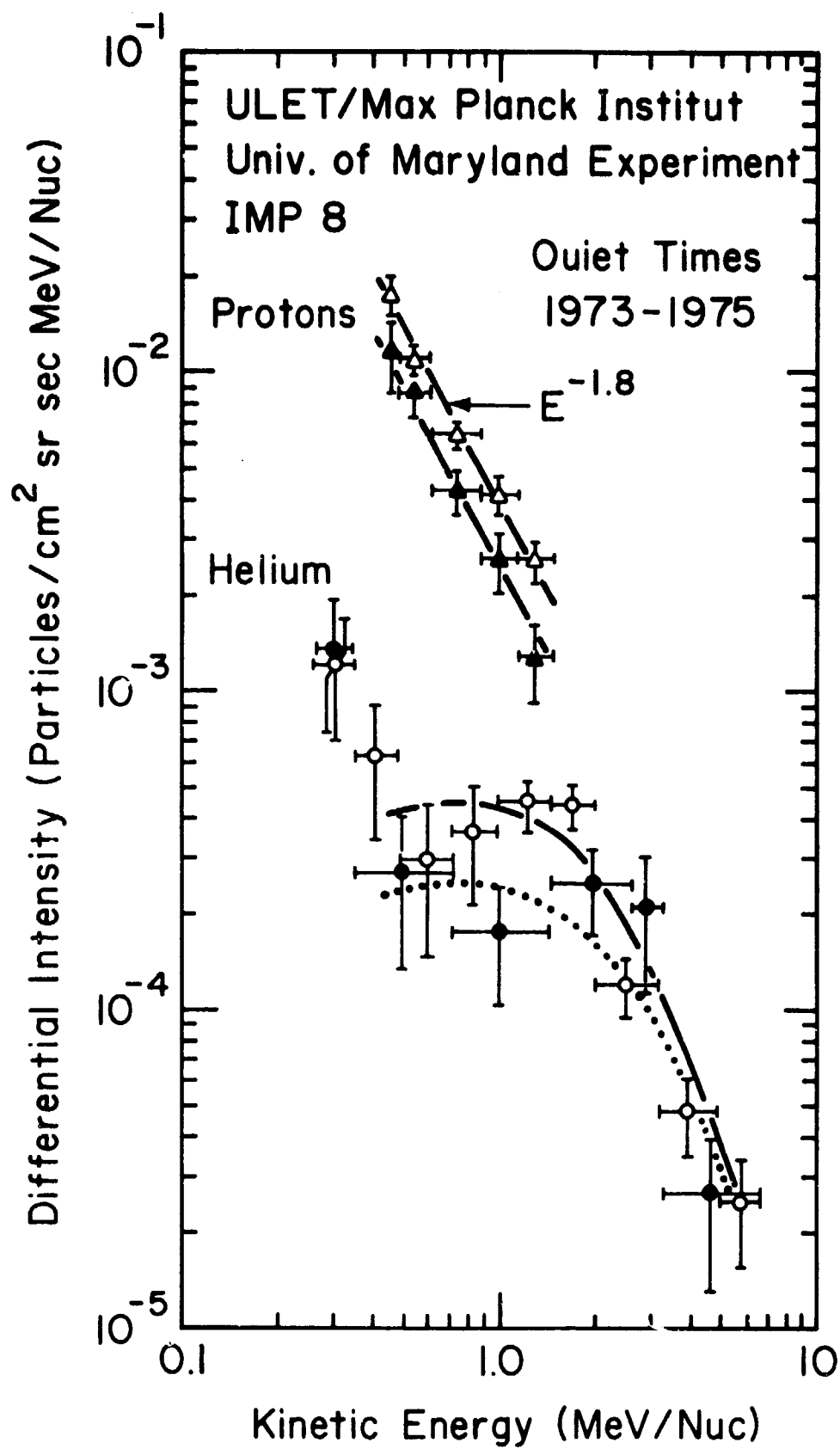


Fig. 4

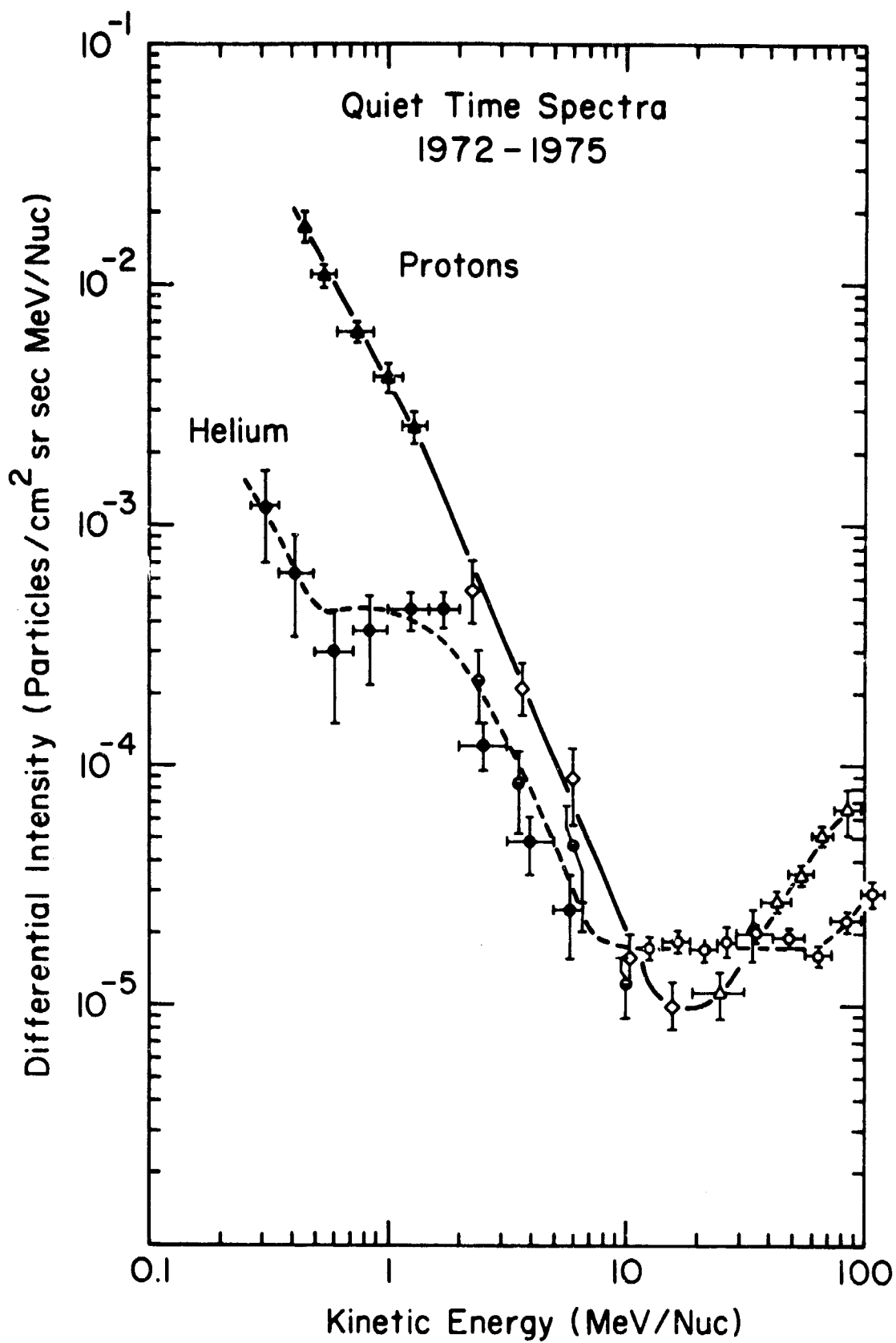


Fig. 5